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MEASUREMENTS OF AN IONIZABLE CONSTITUENT OF THE LOW IONOSPHERE USING A LYMAN-α SOURCE AND BLUNT PROBE

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ABSTRACT

An experiment which measures the density of an ionizable constituent of the D-region (presumably nitric oxide), has been flown successfully on September 22, 1968, December 6, 1968 and December 12, 1968. This experiment uses a blunt probe to detect the changes in conductivity produced by Lyman-α ionizing radiation produced by a flashing microwave discharge in hydrogen behind a lithium fluoride window. The sensitivity of the experiment, which is inversely dependent on velocity, is enhanced by the use of a parachute. The experiment yielded a very positive result, and an analysis of the data yields densities of the ionizable constituent greater than $10^8/cm^3$ in the 40 - 63 km altitude range.

INTRODUCTION

This paper describes recent measurements of a neutral constituent (presumably nitric oxide) which have been made in the 40 - 63 km altitude range. The experiment was originally proposed by R.A. Young in 1963. Basically, the experiment consists of sending a source of radiation into the D-region and measuring the ionization caused by the source.

The changes in conductivity caused by the flashing source are measured by a blunt probe. The basis of the blunt probe technique has been summarized previously by Hale, Hoult, and Baker (1968). The blunt probe utilizes continuium principles to measure polar conductivities of the surrounding medium, the positive conductivity being due to positive ions and the negative conductivity due to contributions from both negative ions and electrons. Using charge neutrality, an assumed reduced mobility for positive and negative ions, drift velocity data for electrons vs. E/P ratios, and an appropriate model atmosphere such as CIRA, 1965, the data can be converted to positive and negative ion and electron densities.

So that no major constituents including the $O_2(^1\Delta g)$ becomes ionized, the source must radiate above 1118 A. However, to ionize the nitric oxide, the source has to radiate below 1340 A which leads to the choice of a Lyman-α source (1216 A). The first prototype of such a source that could be flown as part of a small rocket experiment was designed and built by Gee (1966).

The original calculations by Gee showed, for the simplest case one in which no electron interactions occur, that the electron production by a rocket borne Lyman-α source is given by:

$$P = \frac{n_o N(NO) \sigma_{NO}}{V} \quad (cm^{-3}) \qquad (1)$$

where

n_o = Lyman-α flux at the source in photons $sec^{-1} cm^{-2}$

N(NO) = Concentration of NO molecules per cm^3

σ_{NO} = Photo-ionization cross-section of NO

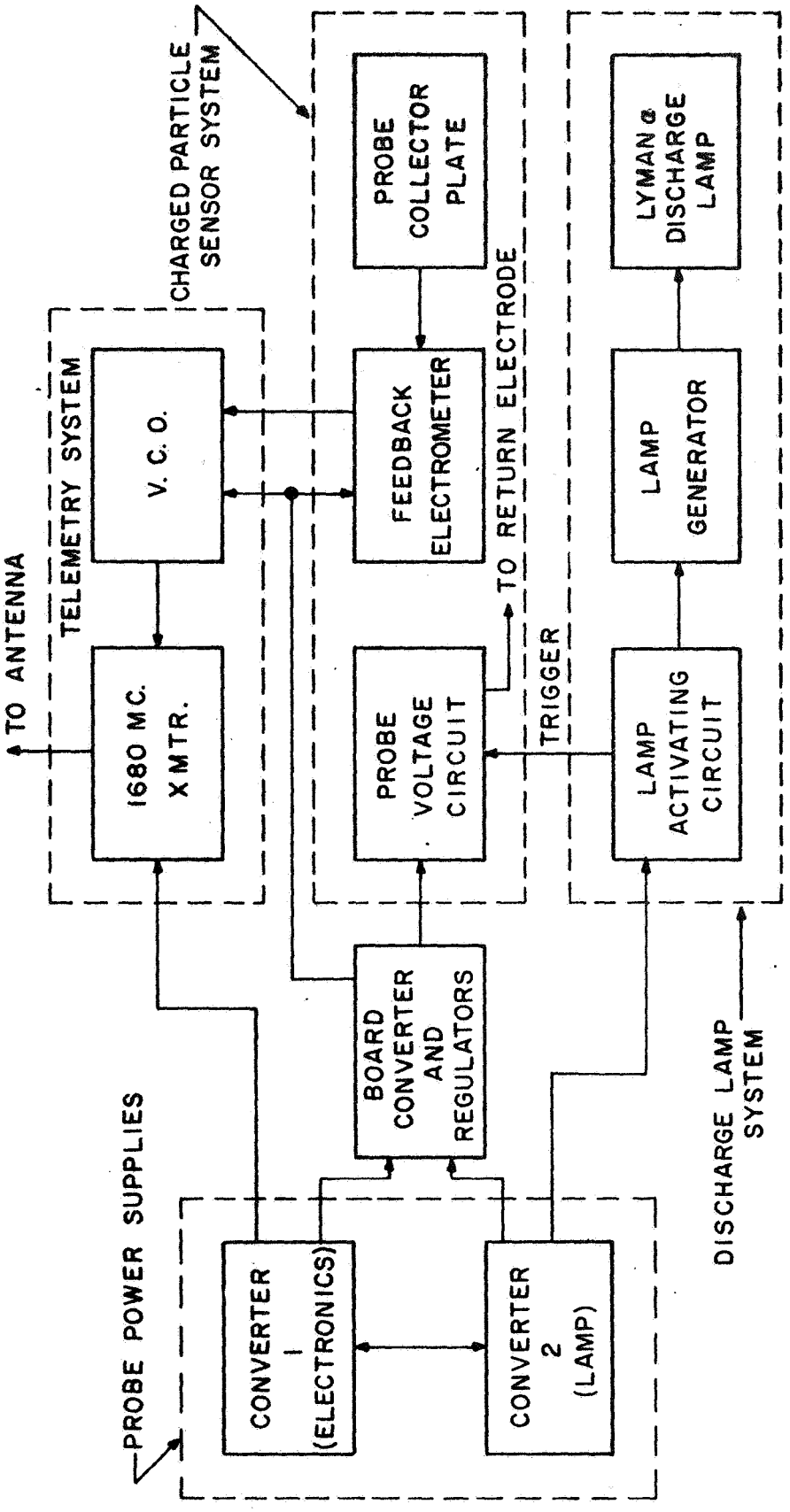
V = Normal velocity of the source.

Since the sensitivity of the experiment is inversely proportional to velocity (eq. 1), a parachute was deployed during descent at which time subsonic measurements were made.

DESCRIPTION OF THE EXPERIMENT

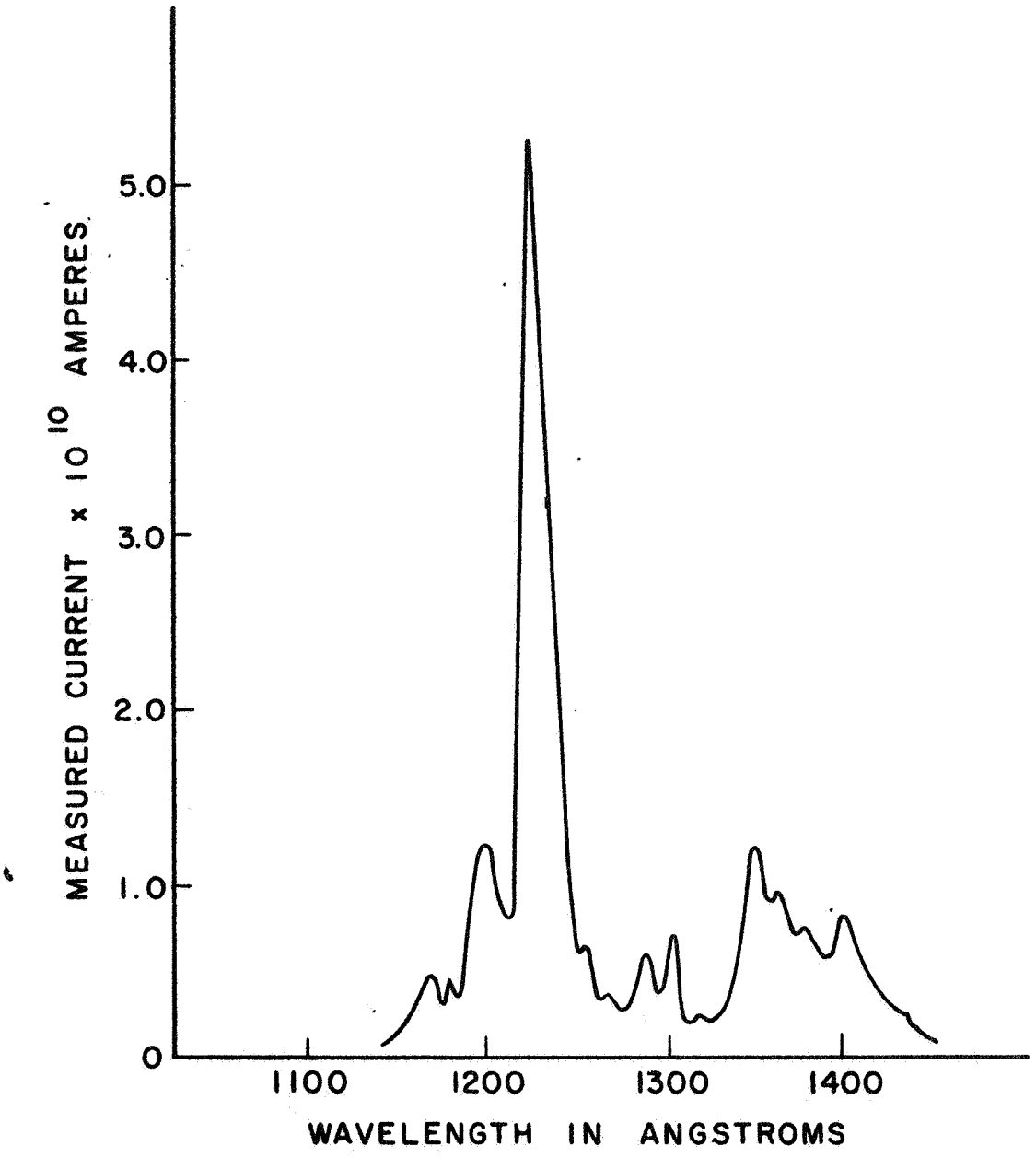
A block diagram of the entire probe system is shown in Fig. 1. The discharge lamp system consists of the Lyman-α source (discharge lamp) which is powered by the lamp generator, a 1680 mc integral tube and cavity oscillating triode. The source consists of a right coaxial cylinder shorted at one end. The lamp cavity was made a quarter wavelength long; therefore, when excited at the shorted end a voltage maximum occurs at the open end. When filled with hydrogen at a pressure of about 1 mm of Hg, a discharge occurs at the voltage maximum (open end) behind a lithium flouride window. The spectrum of the UV source is shown in Fig. 2 displaying no detectable radiation below about 1150 A. The source intensity is about 10^{14} photons sec^{-1} cm^{-2}. The activating circuit is used to turn the source on and off at 5 sec. intervals.

After every "on-off" cycle of the lamp, the probe voltage circuit changes the collection mode between positive and negative conductivity detection. In either mode of operation, current is measured at the collector ring (Fig. 3) by a feedback electrometer. The electrometer output feeds a voltage controlled oscillator which is used to modulate the transmitter.



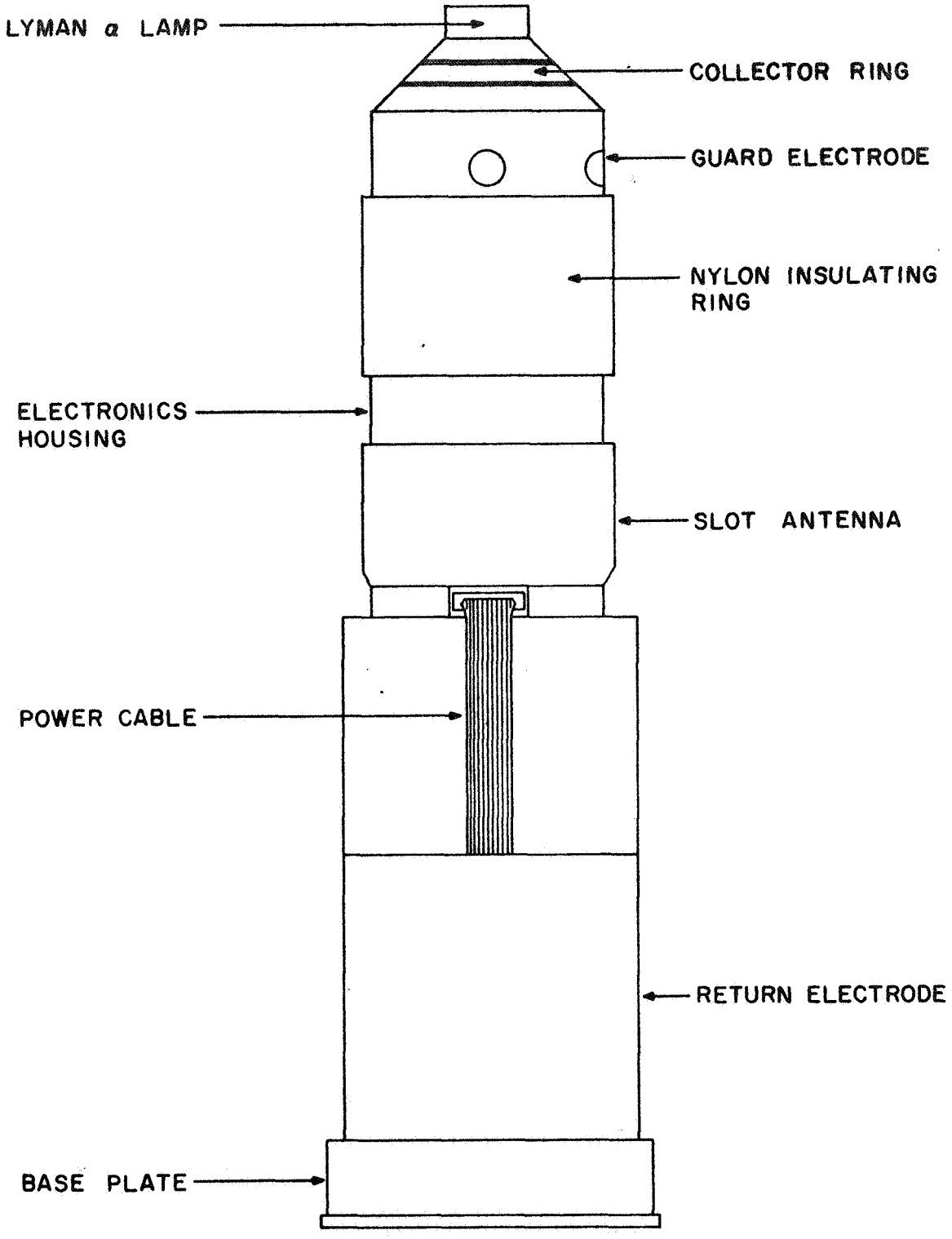
BLOCK DIAGRAM OF NITRIC OXIDE PROBE SYSTEM

FIGURE 1



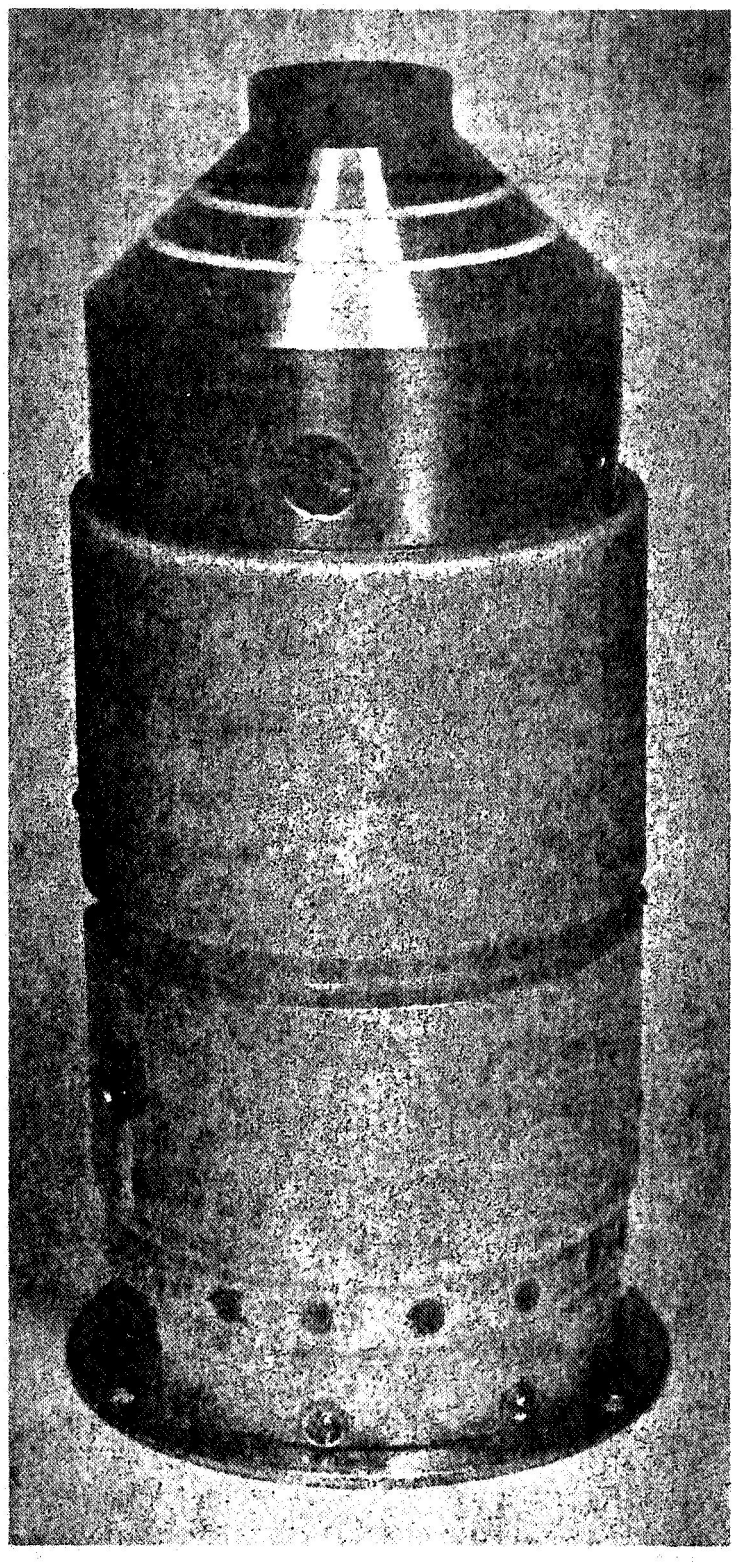
SPECTRUM OF ULTRAVIOLET LAMP USING HYDROGEN

FIGURE 2



EXTERNAL PROBE ASSEMBLY

FIGURE 3a



NITRIC OXIDE PROBE

FIGURE 3b

Two power supply converters and a board converter furnish all power and necessary voltages to the probe.

The major portion of electronics is built into a 4" x 3" diameter drawn aluminum can, shown in Fig. 3. The feedback electrometer is mounted above the aluminum can within the nylon insulating ring. Positioned above the insulating ring is the Lyman-α lamp, housed within the charged particle collecting assembly. The design of the collector assembly enables uniform illumination of the media directly in front of the collector ring while keeping all Lyman-α radiation off of the collector surface. The probe and associated electronics are mounted atop the probe power supplies. Copper foil surrounds the power supplies thus forming the return electrode, which furnishes a return current path to the media.

The total weight of the payload, including nose cone and parachute, is about 14 1/2 pounds with the overall length of 16 inches. The entire probe system consumes about 1 watt of total power.

FLIGHT HISTORY

The initial attempt at measuring NO using this technique was from White Sands Missile Range aboard an Arcas rocket in July of 1968. An equipment failure prior to launch time aborted the flight.

A second try was made on September 24, 1968, at 1840 R.M.S.T. from White Sands Missile Range yielding the first useful data (PSU-NO-1). A radar failure during the greater part of this flight required reconstructing the descent trajectory. This introduced an additional $\pm 30\%$ uncertainty into the data.

On December 6, 1969, at 1805 R.M.S.T., a second successful shot (PSU-NO-2) was flown from White Sands Missile Range. The data indicated a parachute malfunction, causing a high descent velocity. Although this reduced the instrument sensitivity, changes in ionization were still detectable.

Additional useful data was acquired below 50 km on December 12, 1968, at 1805 R.M.S.T. by PSU-NO-3 showing a close repeatability with the first two shots.

DATA ANALYSIS

The experiment was flown after sunset to prevent solar radiation from striking the instrument and contaminating the data. Since the NO was believed to be quickly destroyed after sunset below 70 km, Nicolet (1965), all three shots were flown within a half an hour after sunset at 80 km. Although all three shots were launched after optical sunset at 80 km, the data indicated an abundance of photo-electrons which can only be explained by the presence of scattered solar radiation. The photo-electrons produced a shift in the probe potential of several volts at the higher altitudes, causing the instrument to go off scale; hence, no data was obtained above 63 km. At the lower altitudes, the electric field present at the collector ring (necessary for data reduction) could not be uniquely determined because of the potential shift. Therefore, a blunt probe was fired on December 17, 1968, at 1805 R.M.S.T. from White Sands Missile Range to provide environmental ion densities. The NO probe potential was then determined from the lamp "off" condition when the NO probe measured the environmental ion densities.

Data reduction in the region above 50 km was straight forward since the newly created electrons were collected before interacting with other particles. By measuring the electrons produced by the source, the NO density was obtained by Eq. 1 where P now equals ΔNe, the number of electrons produced by the source.

In the region below 50 km, attachment of electrons to neutrals must be considered because of the increase in attachment coefficient and collection time of the probe. In this case the electron production is given by Gee (1966):

$$\Delta n_e = \frac{n_o N(NO) \sigma_{NO}}{V} \cdot \gamma \qquad (2)$$

where

$\gamma = (1 - A\Delta t)$

and

A = attachment coefficient (Cole and Pierce)

Δt = collection time of the probe (about 10^{-3} sec)

The results of the three shots are shown in Fig. 4.

DATA ACCURACY

Scaling errors on all three shots are believed to be about ± 5 %. Lamp calibration introduces another ± 10% uncertainty into the calculation. Uncertainties in the negative ion densities are on the order of 25% (Hale 1967). The ratio of (μ^- / μ^e) ion to electron mobilities is believed to be known within ± 5 % certainty. Errors in altitude of ± 2 km for shot PSU-NO-1 introduces $\pm$ 20% error into the determination of the environmental ion density and $\pm$ 10% error in the probe velocity.

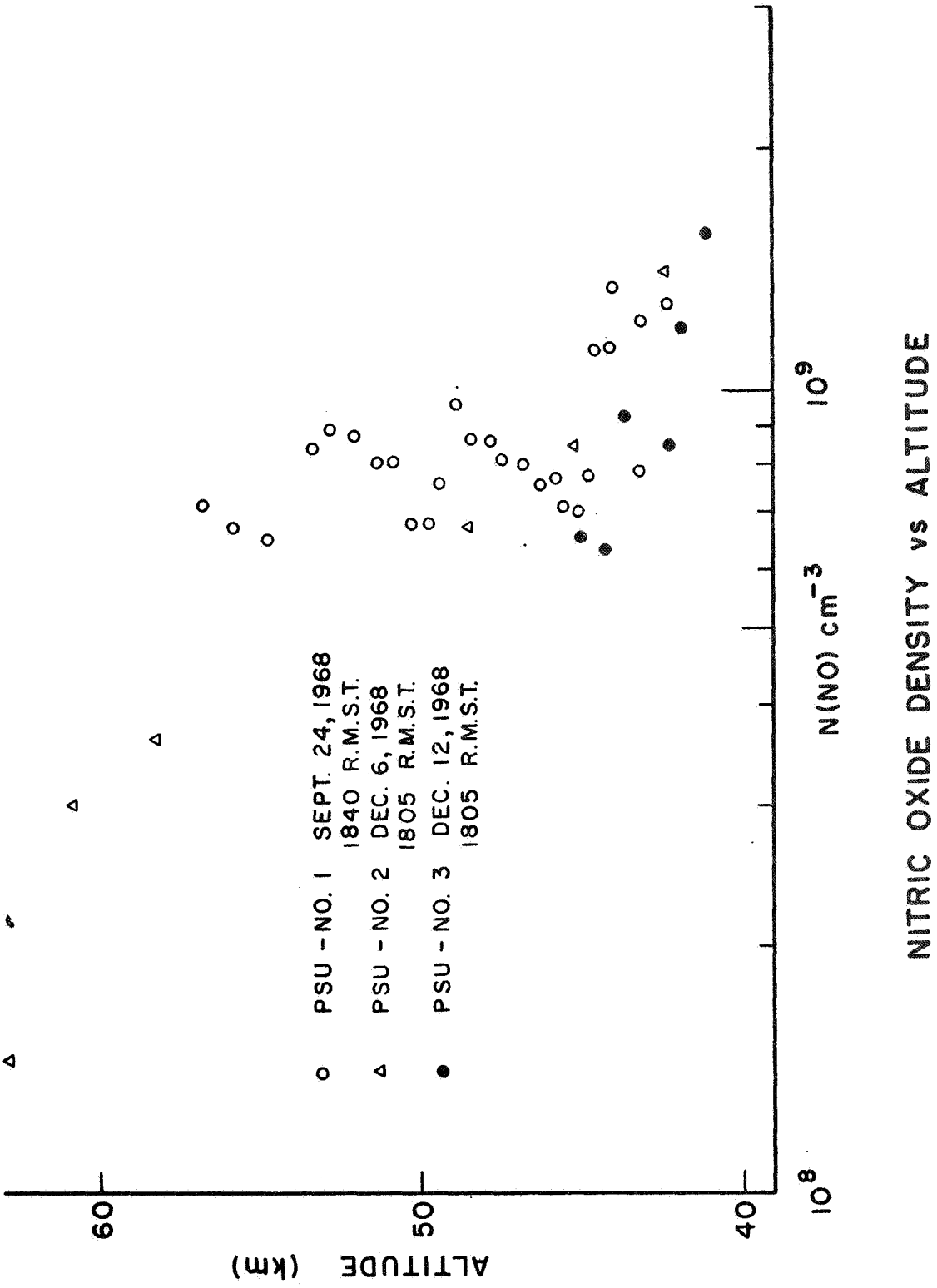

NITRIC OXIDE DENSITY vs ALTITUDE
N(NO) cm⁻³
10⁸
10⁹
ALTITUDE (km)
60
50
40
PSU - NO. 1 SEPT. 24, 1968
1840 R.M.S.T.
PSU - NO. 2 DEC. 6, 1968
1805 R.M.S.T.
PSU - NO. 3 DEC. 12, 1968
1805 R.M.S.T.

FIGURE 4

Thus, the absolute accuracy of the nitric oxide density is about ±75% for PSU-NO-1 and ±45% for PSU-NO-2 and PSU-NO-3. An additional ±10% of uncertainty is introduced, below 50 km, for all three shots in estimating the probe collection time and accuracy of the attachment coefficient.

DISCUSSION OF THE DATA

In the region of 60 km the data appears to be nearly an order of magnitude less than the values of Pearce (1969), which were obtained from rocket measurements of the nitric oxide fluorescence. At this altitude, the data matches well with the values of Baker and Hale (1969), which was calculated from blunt probe positive ion densities made during the course of 1966 solar eclipse.

Although the data tends toward a constant mixing ratio, large deviations exist. These can be explained by the present belief (Nicolet, 1969 and Pearce, 1969) that this region is a sink for NO. Nitric oxide is transported downward into this region and is destroyed by the reaction:

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (3)$$

In view of the fact that the NO profile depends on both the downward transport and the ozone distribution a simple mixing process need not predominate.

In the future, this experiment will be launched later after sunset to avoid the photo-effects and obtain additional data at the higher altitudes.

ACKNOWLEDGEMENT

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